used AHP for as a decision support system for bid evaluation. Tiwari and Banerjee [19] proposed the use of the AHP process as a decision support system for the selection of a casting process, and Kamal [1] used AHP to select the most suitable contractor in the pre-qualification of process of a project. Chandra and Schall [10] used AHP for economic evaluation of flexible manufacturing system using the Leontif input-output model.

The AHP method cannot straightforwardly be applied to solving uncertain decision problems and imprecisely defined ones. In this case, a natural way to cope with such uncertain judgments is to the comparison ratios as fuzzy judgments as fuzzy sets or fuzzy numbers. The fuzzy set theory was proposed by Zadeh [15], and Bellman and Zadeh [22] described the decision making method in fuzzy environment. Laarhoven and Pedrycz [21] proposed the first studies that applied fuzzy logic principle to AHP. Buckley [9] initiated trapezoidal fuzzy numbers to express the decision maker's evaluation on alternatives with respect to each criterion while Laarthoven and Pedrycz were using triangular fuzzy numbers. Chang [5] introduced a new approach for handling fuzzy AHP, with the use of triangular fuzzy numbers for pair-wise comparison scale of fuzzy AHP.

Deng [6] presented a fuzzy approach for tackling qualitative multi-criteria problems in a simple and straightforward manner. Zhu et al. [13] proved the basic theory of the triangular fuzzy number and improved the formulation the triangular fuzzy number's size. Enea and Piazza [17] focused on the constraints that have to be considered within fuzzy AHP. They used constrained fuzzy AHP in project selection. Kahraman et al. [2] used the fuzzy AHP for comparing catering firms in Turkey. Tang and Beynon [26] used fuzzy AHP for the development and application of a capital investment study. They tried to select the type of fleet car to be adopted by a car rental company. Tolga et al. [16] used fuzzy replacement analysis and AHP in the selection of operating system. Chan and Kumar [3] proposed a model for providing a framework for an organization to select the global supplier by considering risk factors. They used fuzzy extended AHP in the selection of global supplier in the current business scenario. Cheng and Tang [11] studied the selection of appropriate fourth party logistics company in business. They attempted to identify evaluation factors and their weight in the selection process. Fuzzy Analytic Hierarchy Process (FAHP) was utilized to calculate the weight of the various factors. Yang Wu et al. [14] constructed a three hierarchal evolution model to assess disaster prevention in Miaoli County in Taiwan. FAHP was applied for multivariable analyses between interacting and its prevention preparation. Cheng and Tang [11] attempted to identify the critical factors related to bicycle supplier selection. Fuzzy Delphi method and FAHP were used to calculate the weight of the different criteria in order to construct a fuzzy multi-criteria model of bicycle selection. Chiang and Wang [27] assessed management competencies of middle managers, from the point view of supervisors, the candidates for middle managers using FAHP. The result provided ranking of the middle managers on the bases on their management competency. In their work, Jiang et al. [25] coupled the AHP and a fuzzy comprehensive evaluation method to form a new approach. This approach was used to facilitate pair-wise comparison and avoid complex and unreliable process of comparing fuzzy utilities.

Lee [28] studied issued related to the selection of supply chain manager. He suggested that this is a multi-criteria decision making (MCDM) problem since it requires to consider a large number of complex factors. Since many MCDM methods are based on the independence assumptions. He proposed using the Analytic Network Process (ANP) which can deal with all kinds of dependencies, He proposed a method combining multiple intelligence theory with ANP. An empirical study was presented to illustrate the application of his method.

Mainabadi et al. [7] studied the complexity of water resource management issues and its relation to other sciences. The aim of his work was to develop a new process for consensus-based heterogeneous group decision making models. In addition to introducing the decision making process and studying its efficiency in integrated water resources planning and management was presented.

Huang et al. [4] built five models for five insurances, respectively, including life, annuity, health, accident, and investment-oriented insurances. The proposed models consist of AHP, fuzzy logic and Delphi technique. Four variables were selected as the inputs including age, annual income, educational level and risk preference. Using trapezoidal membership function, these input were transformed to fuzzy variables. Twenty experts with many years of experience were interviewed to build these models.

FAHP approach is based on fuzzy concepts with was proposed by Lofti Zadeh. Fuzzy sets and logic are powerful mathematical tools modelling uncertain systems in many scientific, economic, and social fields; and are facilitators for common-sense reasoning in decision making in the absence of complete and precise information. A fuzzy set is an extension of a crisp set; crisp sets only allow full membership or non-membership at all, whereas fuzzy sets allow partial memberships. Zadeh, proposed to use values ranging from 0 to 1 for showing the membership of the objects in a fuzzy set. Here, complete membership is represented as 1 and complete non-membership as 0. Values between 0 and 1 represent intermediate degrees of membership

Fuzzy numbers are a special form of fuzzy sets, a fuzzy number is a fuzzy quantity $\widetilde{N}$ that represents a generalization of a real number *r*, thus is used to approximate *r*. A fuzzy number $\widetilde{N}$ is a convex normalized fuzzy set (Nguyen and Walker [6]. A fuzzy number is characterized by a given interval of real numbers, each grade of membership between 0 and 1.

Triangular fuzzy numbers (TFN) are used in this study; Triangular fuzzy numbers are a special case of fuzzy number [4]. A triangular fuzzy number $\widetilde{N}$ is defined by three real numbers, expressed as (*l,m,u*), where *l* is the lowest possible vale, *m* indicating the most promising value, and *u* indicating the largest possible value that describe the fuzzy event. It is characterized by a linear piecewise continuous membership function $\mu_{\widetilde{N}}(x)$ which is described as:

$$\mu_{\tilde{N}}(x) = \begin{cases} 0 & x < l \\ (x-l)/(m-i) & l \le x \le m \\ (u-x)/(u-m) & m \le x \le u \\ 0 & x > u \end{cases} \quad (1)$$

A triangular fuzzy number $\widetilde{N}$ is represented graphically as shown in Fig. 4.

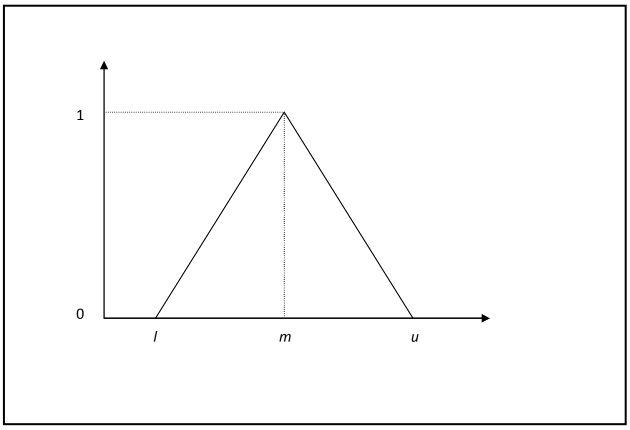

Fig. 4, A triangular fuzzy number, $\widetilde{N}$.

The basic theory of FAHP is as follows: assume the problem under study has *n* independent alternatives $(\widetilde{A}_1, \widetilde{A}_2, ..., \widetilde{A}_n)$ with the weights $(\widetilde{w}_1, \widetilde{w}_2, ..., \widetilde{w}_n)$ respectively. The decision maker does not know in advance the values of $\widetilde{w}_i$, i = 1,2,…,*n*, but he/she is capable of making pair-wise comparisons between the different alternatives. Also, assume that the quantified judgments provided by the decision maker) on pairs of alternatives $(\widetilde{A}_i, \widetilde{A}_j)$ are represented in an *n*×*n* a fuzzy comparison matrix $\widetilde{A} = \{\widetilde{a}_{ij}\}$ is constructed as:

$$\widetilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} ....\tilde{a}_{1n} \\ \tilde{a}_{21} & 1..........\ \tilde{a}_{2n} \\ : & :::\ :::::::\ : \\ \tilde{a}_{n1} & \tilde{a}_{n2}.........\ 1 \end{bmatrix} \quad (2)$$

Where a fuzzy triangular numbers $\widetilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ with the following properties:

1. $\widetilde{a}_{ij} \approx \widetilde{w}_i / \widetilde{w}_j, i, j = 1,2,......, n$.
2. $\widetilde{a}_{ii} = 1,\ i = 1,2,....., n.$ All diagonal cells have the value 1.
3. $\widetilde{a}_{ji} = 1/\widetilde{a}_{ij} \approx \widetilde{w}_j / \widetilde{w}_i, i, j = 1,2,......, n$.
4. $\widetilde{a}_{ij} \cong (\widetilde{w}_i / \widetilde{w}_j) > 1, i, j = 1,2,......, n$, If $\widetilde{A}_i$ is more preferred than $\widetilde{A}_j$.

This implies that matrix $\widetilde{A}$ is a positive and reciprocal matrix with 1's in the main diagonal and hence the decision maker should only provide value judgments in the upper triangle of the matrix. The values assigned to $\widetilde{a}_{ij}$ according to Saaty (AHP) scale are usually in the interval of 1–9 or their reciprocals. Table 3 presents Saaty's scale of preferences in the pair-wise comparison process.

Table 3, AHP Scale of Preferences in the Pair-Wise Comparison Process

Numerical Ratings	Verbal Judgements of Preferences between Alternative *i* and Alternative *j.*
1	*i* is equally preferred to *j*
3	*i* is slightly more preferred than *j*
5	*i* is strongly more preferred than *j*
7	*i* is very strongly more preferred than *j*
9	i is extremely more preferred than *j*
2,4,6,8	Intermediate values

The following are the main steps of FAHP:

1. State the overall objective of the problem and identify the criteria that influence the overall objective.
2. Structure the problem as a hierarchy of goal, criteria, sub-criteria, and alternatives.
3. Start by the second level of the hierarchy:
   - Do pair-wise comparison of all elements in the second level and enter the judgments in an $n \times n$ matrix. The values assigned to $\tilde{a}_{ij}$ according to Saaty (AHP) scale are usually in the interval of 1–9 or their reciprocals.
   - Calculate the fuzzy priorities by first finding the fuzzy geometric mean geometric for the different rows of the pair-wise comparison of the matrix. Next, the resulting vectors are normalized by dividing each entry by the sum of entries in the vector. The fuzzy geometric mean (*FGM*) is calculated as follows:

$$FGM = \prod_{j=1}^{n} (\tilde{a}_{ij})^{1/n} \quad ,i = 1,2,......,n \qquad (3)$$

   Compute the consistency ratio of the matrix of judgments to make sure that the judgments are consistent.
4. Repeat step 3 for all elements in a succeeding level but with respect to each criterion in the preceding level.
5. Synthesize the local priorities (fuzzy local weights) over the hierarchy to get a priority (fuzzy composite weight) for each alternative.
6. Defuzzifying the resulted fuzzy values of the fuzzy composite weight in order to obtain a crisp value using the Centre of Area method which calculate using the relationship in 5:

$$CN_{ij} = \frac{[(u_{ij} - l_{ij}) + (m_{ij} - l_{ij})]}{3} + l_{ij} \qquad \forall i, j \qquad (4)$$

4 Application of FAHP for Policy Prioritization for Water Conservation in Kuwait

Several factors must be considered in selecting a desalination process, they include the following:

1. Product Water Recovery ratio as a function of the feed: The ratio of the amount of the freshwater to the amount of the input seawater. The higher the better.
2. Energy Requirement: The amount of energy required to produce freshwater (KW/M^3), the lower the better.
3. Pretreatment Requirements (PRR): The intensity of the pretreatment required by the input sea water prior to desalination. It various from one technology to another, technology with less pretreatment required are more preferable.
4. Product water Salinity (PWS): The concentration of salt in the desalinated water, the less the better.
5. Turnkey Capital Investment Cost (TCQ): The total cost charged by the contractor constructing the plant. The technology with the least cost is proffered.
6. Corrosion potential (CPO): The amount of annual corrosion accumulated in the various equipments due to the operation of the plant.

Table 4 shows the performance of the different desalination technologies in the various factors. This was constructed by consulting several experts with many years of expertise in this field in the region.

Table 4, Linguistic Evaluation of the Different Desalination Technologies for the Various Criteria

Parameter	MSF	RO	MED
PRR	Low	Very high	Low
PWS	Low	Medium	Low
WRR	Low	High	Medium high
TCQ	High	Low	Medium
ERQ	High	Low	Medium
CPO	High	Low	Medium high

4.1 Pair-wise comparisons

The hierarchy of the decision problem as shown in Fig. 5 has three levels. The first level is the goal, the second level presents the criteria and the bottom level presents the alternatives. Several water experts in Kuwait were consulted in order to form the different pair-wise comparison matrices.

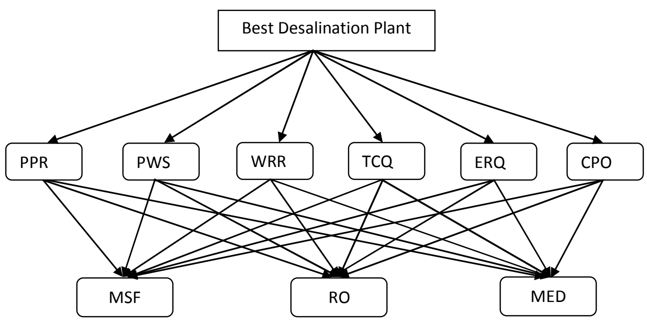

Fig 5, Analytic hierarchy of desalination plant selection.

In Tables 5, and 6 the different linguistic terms and comparisons were translated into fuzzy numbers. Table 5 shows the preference between the various criteria, while Table 6 is for comparing the different technologies.

Table 5, Fuzzy Values for the Different Linguistic Scales of the Criteria

Linguistic Scales	Scale of Triangular fuzzy number
Absolutely important	(7,9,9)
Very strongly important	(5,7,9)
Essentially important	(3,5,7)
Weakly important	(1,3,5)
Equally important	(1,1,3)

Table 6, Fuzzy Values for the Different Linguistic Scales of the Alternatives

Linguistic Scales	Scale of Triangular Fuzzy Number	
	Maximize	Minimize
Very high	(9,10,10)	(1,1,3)
High	(7,9,10)	(1,3,5)
Medium high	(5,7,9)	(3,5,7)
Medium	(3,5,7)	(5,7,9)
Medium low	(1,3,5)	(7,9,10)
Low	1,1,3)	(9,10,10)

Tables 7-13 present the pair-wise comparisons between the different desalination technologies with respect to each criterion, similarly he geometric mean and the normalized geometric mean is calculate in all cases.

4.2 Synthesizing judgments

The last step in the FAHP is synthesizing of judgments were the composite weight of the different desalination technologies are determined by combining the fuzzy priorities of the different criteria (factors) as given in Table 9 and that of the different technologies under each criteria as has been calculated in Tables 10-14. Table 15 presents the fuzzy composite weight.

Next the crisp composite weight is calculated through defuzzification process using the centre of area method using the relationship in 4. The composite weight of the different technologies become after normalization becomes follows: MSF (0.232), RO (0.401), and MED (0.367).

5 Results and Conclusion

The results of the analysis shows that the most important criteria to consider when selecting any desalination technology is selecting any water desalination technology is the amount of energy required (ERQ =0.378), followed by the pre-treatment requirement (PRR = 0.250), next come the product water recovery ratio (WRR = 0.167), turnkey capital investment cost (TCQ = 0.0996), product water salinity (PWS = 0.066), and corrosion potential (0.043). With respect to water technology type, reverse osmosis came first with 0.401 (40.1%), followed closely by multi-effect distillation (MED) with 0.367 (36.7 %), last is multi-flash desalination with 0.232 (23.2 %). It is apparent that energy requirement should be considered when selecting any technology; in Kuwait energy used in the existing desalination plant is around 5 billion dollars per day. Moreover, pre-treatment and capital are also very important and should be paid attention to in the selection process. Kuwait has to consider building reverse or multi-effect distillation plants in the future.

Table 7, Pair-wise Comparison of Criteria with respect to the Goal

Criteria	PPR	PWS	WRR	TCQ	ERQ	CPO	Mean of the relative weight	Normalized Mean of the relative weight
PPR	(1,1,1)	(3,5,7)	(1,1,3)	(1,3,5)	(1,1,1/3)	(5,7,9)	(224,.236,.258)	(.236,.246,.267)
PWS	(1/7,1/5,1/3)	(1,1,1)	(1/5,1/3,1)	(1/3,1,1)	(1/9,1/7,1/5)	(1,1,3)	(.055,.066,.069)	(,057,.069,.072)
WRR	(1,1,3)	(1,3,5)	(1,1,1)	(1,1,3)	(1/5,1/3,1)	(3,5,7)	(.138,.156,.186)	(.144,.161,.196)
TCQ	(1/5,1/3,1)	(1,1,3)	(1/3,1,1)	(1,1,1)	(1/7,1/5,1/3)	(1,3,5)	(.09,.091,.112)	(.087,.094,.118)
ERQ	(1,1,3)	(5,7,9)	(1,3,5)	(3,5,7)	(1,1,1)	(7,9,9)	(.323,.373, 392)	(.340,.385,.409)
CPO	(1/9,1/7,1/5)	(1/3,1,1)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1/9,1/9,1/7)	(1,1,1)	(035,.040,.040)	(.036,.042,.042)

Table 8, Pair-wise Comparison of the different technologies with respect to PRR

Technology	MSF	RO	MED	Mean of the relative weight	Normalized Mean of the relative weight
MSF	(1,1,1)	(3.33,9,10)	(1,1,1)	(1.493,2.08,2.15)	(.435.474,. 476)
RO	(.1,.111,.3)	(1,1,1)	(.1,.111,.3)	(.215,.231,.448)	(.048,.052, .130)
MED	(1,1,1)	(3.33,9,10)	(1,1,1)	(1.494,2.08, 2.15)	(.435,.474,.476)

Table 9, Pair-wise Comparison of the different technologies with respect to PWS

Technology	MSF	RO	MED	Mean of the relative weight	Normalized Mean of the relative weight
MSF	(1,1,1)	(1, 1.666,3)	(1,1,1)	(1,1.285,1.44)	(.333, .385,.429)
RO	(.333,.6,1)	(1,1,1)	(.333,.6,1)	(.481,.712, 1)	(.143,.230,.333)
MED	(1,1,1)	(1, 1.666,3)	(1,1,1)	(1,1.285,1.44)	(.333,.385,.429)

Table 10, Pair-wise Comparison of the different technologies with respect to WRR

Technology	MSF	RO	MED	Mean of the relative weight	Normalized Mean of the relative weight
MSF	(1,1,1)	(.111,.3,.143)	(.143,.2,.333)	(.251,.306,.464)	(.059,.077,.136)
RO	(3.333,7,9)	(1,1,1)	(1.111,1.28,1.4)	(1.55,2.14, 2.26)	(.455,.529,.538)
MED	(3,5,73)	(.714,.778,.9)	(1,1,1)	(1.39,1.53, 1.76)	(.385,.409,.412)

Table 11, Pair-wise Comparison of the different technologies with respect to TCQ

Technology	MSF	RO	MED	Mean of the relative weight	Normalized Mean of the relative weight
MSF	(1,1,1)	(.111,.3,.5)	(.33,.43,.56)	(.333,.505,.652)	(.077,.15,.208)
RO	(2,3.33, 9)	(1,1,1)	(1.11,1.43,3)	(1.305, 1.682,3)	(.417,.5,.692)
MED	(1.8,2.33, 3)	(.333,.7,.9)	(1,1,1)	(1, 1.744,1.778)	(.231, .35,.375)

Table 12, Pair-wise Comparison of the different technologies with respect to ERQ

Technology	MSF	RO	MED	Mean of the relative weight	Normalized Mean of the relative weight
MSF	(1,1,1)	(.111,.3,.5)	(.2,.429, .9)	(.281,.505,.766)	(.067,.15,.243)
RO	(2,,3.333,9)	(1,1,1)	(1.43,1.8,1.8)	(1.533, 1.68, 2.53)	(.5,.486,.6)
MED	(1.11,2.33,5)	(.55,.55,.7)	(1,1,1)	(.851,1.177,1.406)	(.270,.333, .35)

Table 13, Pair-wise Comparison of the different technologies with respect to CPO

Technology	MSF	RO	MED	Mean of the relative weight	Normalized Mean of the relative weight
MSF	(1,1,1)	(.111,.3,.5)	(.333,.6,.714)	(.333,.564,.709)	(.077,.167,.227)
RO	(2,3.33,9)	(1,1,1)	(,1.428,2,3)	(1.419,1.88,3)	(.454,.556,.692)
MED	(3,1.667,1.4)	(.333,.5,.7)	(1,1,1)	(.941,.993,1)	(.231 .278,.318)

Table 14, Pair-wise Comparison of Criteria with respect to the Goal

Criteria	PPR (.236,.246,.267)	PWS (.072,057,.069)	WRR (.144,.161,.196)	TCQ (.087,.094,.118)	ERQ (.409,.385,.340)	CPO (.042,0.036,.042)	Fuzzy Composite weight
MSF	(.435.474,. 476)	(.333,.385,.429)	(.059,.077,.136)	(.077,.15,.208)	(.067,.15,.243)	(.077,.167,.227)	(.167,.226,.283)
RO	(.048,.052, .130)	(.143,.230,.333)	(.455,.529,.538)	(.417,.5,.692)	(.5,.486,.6)	(.454,.556,.692)	(.339,.373,.462)
MED	(.435,.474,.476)	(.333,.385,.429)	(.385,.409,.412)	(.231, .35,.375)	(.270,.333, .35)	(.231 .278,.318)	(.312,.374,.385)

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